Hadron Chemistry at High P_T with Identified Particles

Rainer J. Fries

Cyclotron Institute, Texas A&M University, College Station, TX 77845, USA
and
RIKEN/BNL Research Center, Brookhaven National Laboratory, Upton NY 11973, USA

Abstract. We discuss mechanisms that change the hadron chemistry for high momentum particles emitted in high energy nuclear collisions. We argue that particle ratios naturally tend to be different from jets in the vacuum. We show results of computations in a model that propagates leading particles through a quark gluon plasma and permits elastic flavor changing processes. We predict less suppression for kaons compared to pions in central collision. We also discuss elliptic flow resulting from flavor changing processes.

Keywords: Heavy Ion Collisions, Quark Gluon Plasma
PACS: 24.85.+p,25.75.Bh

QCD jets have been used as probes of hot nuclear matter since the start of the experimental program at the Relativistic Heavy Ion Collider (RHIC). The first results from RHIC showed a huge suppression of single inclusive particle yields at high transverse momenta, consistent with a large energy loss of fast partons in the quark gluon plasma created in the collisions. This quenching of jets is often parameterized by the rate of squared momentum transferred from the medium to a parton traversing it, $\hat{q} = \mu^2/\lambda$ where λ is the mean free path of the parton in the plasma [1, 2, 3, 4, 5, 6].

It was recently pointed out that the chemical composition of jets is expected to change from the vacuum as well. Two models have been proposed to describe this effect. In a leading particle picture one considers an ensemble of jets described by their leading parton which propagates through quark gluon plasma while interacting with it. The chemical composition of this jet or leading particle ensemble changes through flavor changing scatterings. E.g., Compton and annihilation reactions like $q+g \leftrightarrow g+q$ and $q+\bar{q} \leftrightarrow g+g$ can change quark jets into gluon jets and vice versa. Leading partons are fragmented once they are outside the medium which translates a changing parton chemistry into a hadron chemistry which is different from $p+p$ collisions [7, 8, 9, 10, 11].

In a second approach one can study the changing chemical composition inside a single jet cone that comes from increased multiplicities. Additional induced radiation inside a jet cone is more favorable for the creation of baryons and kaons compared to the vacuum [12]. It is clear that both mechanisms play a role and a complete description of data would successfully implement a chemical coupling to the medium and increased parton multiplicities. Here, we will focus on the former model.

Conversions between leading quark and gluon jet particles can potentially answer the question why there are no signs of the additional color factor 9/4 in the quenching of

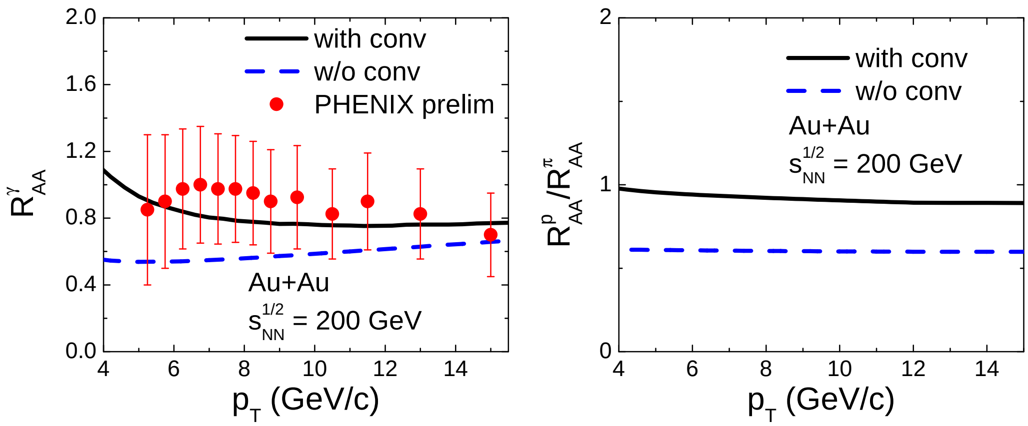

FIGURE 1. Left panel: The nuclear modification factor R_{AA} for direct photons with and without conversions switched on, calculated in the model introduced in [10] (preliminary PHENIX data from [20]). Right panel: The ratio of nuclear modification factors for protons and pions is approaching one if conversions are allowed.

gluons. Hadrons that favor fragmentation from gluons more than others should exhibit smaller modification factors R_{AA}. The data is pointing in the exactly opposite direction: protons are less suppressed than pions, even for momenta of 10 GeV/c or more [13]. It has been demonstrated that conversions can effectively blur the distinction between well-defined quark or gluon jets. The right hand side of Fig. 1 shows the increase in proton R_{AA} to the value of the pion R_{AA} with conversions computed in [10]. However, while conversions increase relative proton suppression to the level of pions it can not explain the data from STAR which shows even less suppression for protons [13]. More work needs to go into understand baryons in heavy ion collisions. It could be speculated that soft physics like quark recombination [14] is still contributing to baryon production at those large momenta.

Historically, the first application of conversions of leading jet partons was carried out for photon and dileptons. Annihilation and Compton processes of jets with partons from the medium can lead to hard photon emission [7, 15, 16, 17]. This additional photons source is now routinely integrated in state-of-the-art calculations of photon spectra [16, 18, 19]. Fig. 1 shows the nuclear modification factor for direct photons from [10]. Recently we also predicted that strange hadrons should be enhanced in heavy ion collisions at RHIC energies [10]. Strange quark jets are rare at RHIC, while strange quarks are chemically equilibrated in the quark gluon plasma. Interactions between jets and the medium should therefore drive the jet ensemble toward chemical equilibration. through pair creation and kick out reactions of existing strange quarks in the medium. This will translate into an increased R_{AA} of kaons as shown in Fig. 2.

We have checked that the same mechanism leads to a negligible enhancement of heavy charm and bottom quarks at high momentum both at RHIC and LHC energies [21]. The main reasons are the large thresholds for pair creation and the small amount of primordial heavy quarks in the medium which makes kick out reactions ineffective.

A more recent development have been considerations of the azimuthal asymmetry coefficient v_2 for particles emerging from jet conversions. It was first pointed out for

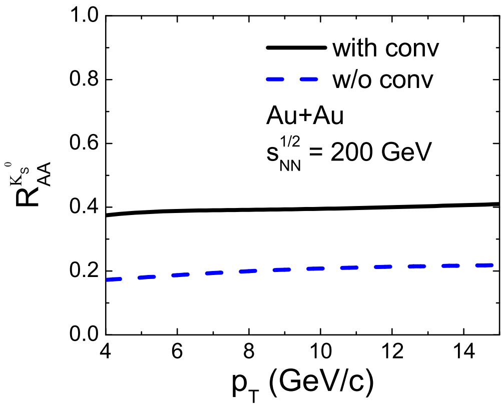

FIGURE 2. R_{AA} for neutral kaons with and without conversion processes allowed. The strangeness in the jet sample is driven towards equilibrium by coupling it chemically to the quark gluon plasma.

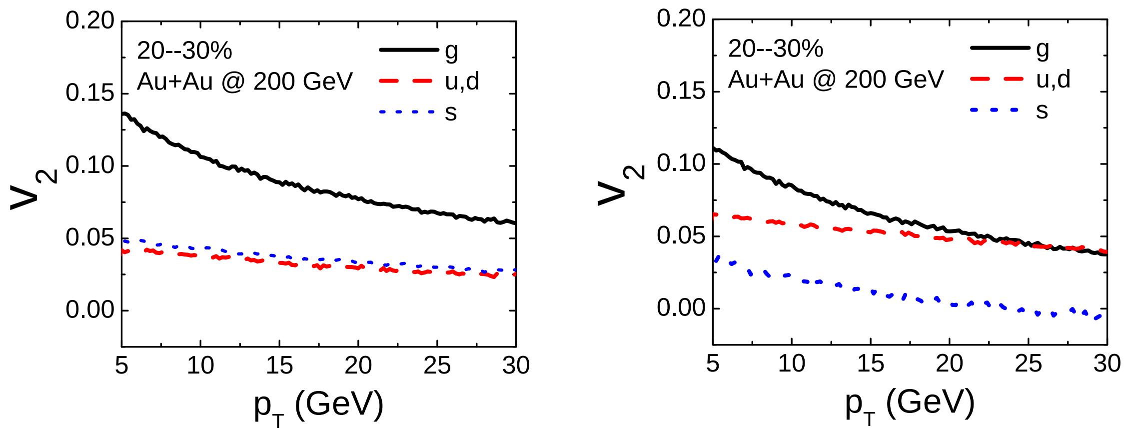

FIGURE 3. Left panel: The azimuthal asymmetry v_2 for light quarks, strange quarks and gluons without conversions. Right panel: the same with conversions. The v_2 for light quarks and gluons is not similar, while strange quarks exhibit a suppression.

photons that there are more conversions if a parton has to travel through thicker material, thus rendering the elliptic flow coefficient v_2 negative for the conversion product [22]. After adding photons from other sources the resulting v_2 is positive but numerically very small. First preliminary data from PHENIX on photon v_2 at large momentum is still inconclusive [22, 23, 10]. We advocate similar efforts to measure the v_2 of strange hadrons at high P_T. Just like photons, strange quarks from jet conversions should have negative v_2. Adding all sources we predict a suppression of the v_2 for strange quarks compared to gluons and light quarks and hence a suppression of the v_2 of kaons compared to pions [24], see Fig. 3 and 4.

This work was supported by RIKEN/BNL Research Center and DOE grant DE-AC02-98CH10886.

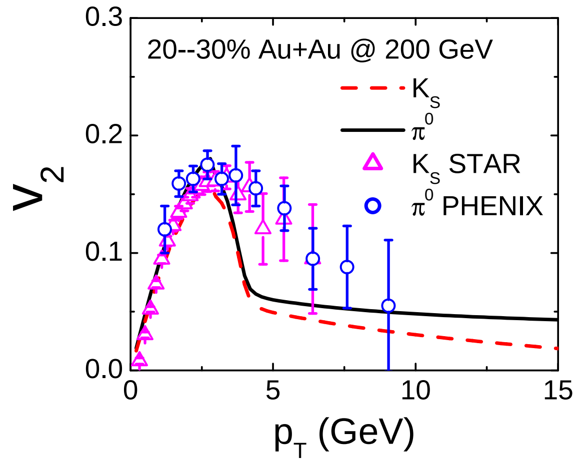

FIGURE 4. The resulting azimuthal asymmetry v_2 for kaons which is expected to be suppressed compared to that of pions. Data from [25, 26].

REFERENCES

1. X. N. Wang, and M. Gyulassy, *Phys. Rev. Lett.* **68**, 1480 (1992).
2. R. Baier *et al.*, *Nucl. Phys. B* **483**, 291 (1997); *Nucl. Phys. B* **484**, 265 (1997).
3. B. G. Zakharov, *JETP Lett.* **63**, 952 (1996).
4. U. A. Wiedemann, *Nucl. Phys. A* **690**, 731 (2001).
5. M. Gyulassy, P. Levai, and I. Vitev, *Phys. Rev. Lett.* **85**, 5535 (2000); *Nucl. Phys. B* **594**, 371 (2001).
6. P. Arnold, G. D. Moore, and L. G. Yaffe, *JHEP* **0206**, 030 (2002); S. Jeon, and G. D. Moore, *Phys. Rev. C* **71**, 034901 (2005).
7. R. J. Fries, B. Muller, and D. K. Srivastava, *Phys. Rev. Lett.* **90**, 132301 (2003).
8. W. Liu, C. M. Ko, and B. W. Zhang, *Phys. Rev. C* **75**, 051901 (2007); *Int. J. Mod. Phys. E* **16**, 1930 (2007).
9. C. M. Ko, W. Liu, and B. W. Zhang, *Few Body Syst.* **41**, 63 (2007).
10. W. Liu, and R. J. Fries, *Phys. Rev. C* **77**, 054902 (2008).
11. R. J. Fries, arXiv:0907.4390 [nucl-th]; R. J. Fries and W. Liu, arXiv:0907.4802 [nucl-th].
12. S. Sapeta, and U. A. Wiedemann, *Eur. Phys. J. C* **55**, 293 (2008).
13. B. I. Abelev *et al.* [STAR Collaboration], *Phys. Rev. Lett.* **97**, 152301 (2006); Y. Xu, arXiv:0907.4644 [hep-ph].
14. R. J. Fries, B. Muller, C. Nonaka, and S. A. Bass, *Phys. Rev. Lett.* **90**, 202303 (2003); R. J. Fries, *J. Phys. G* **30**, S853 (2004).
15. R. J. Fries, B. Muller, and D. K. Srivastava, *Phys. Rev. C* **72**, 041902 (2005).
16. D. K. Srivastava, C. Gale, and R. J. Fries, *Phys. Rev. C* **67**, 034903 (2003); S. Turbide, C. Gale, D. K. Srivastava, and R. J. Fries, *Phys. Rev. C* **74**, 014903 (2006).
17. C. Gale, T. C. Awes, R. J. Fries, and D. K. Srivastava, *J. Phys. G* **30**, S1013 (2004).
18. S. Turbide, C. Gale, S. Jeon, and G. D. Moore, *Phys. Rev. C* **72**, 014906 (2005).
19. S. Turbide, C. Gale, E. Frodermann, and U. Heinz, *Phys. Rev. C* **77**, 024909 (2009).
20. S. S. Adler *et al.* [PHENIX Collaboration], *Phys. Rev. Lett.* **94**, 232301 (2005).
21. W. Liu and R. J. Fries, *Phys. Rev. C* **78**, 037902 (2008).
22. S. Turbide, C. Gale and R. J. Fries, *Phys. Rev. Lett.* **96**, 032303 (2006).
23. R. Chatterjee *et al.*, *Phys. Rev. Lett.* **96**, 202302 (2006); *Phys. Rev. C* **75**, 054909 (2007).
24. W. Liu, and R. J. Fries, arXiv:0805.3721 [nucl-th].
25. D. Winter, *Nucl. Phys. A* **774**, 545 (2006).
26. B. I. Abelev *et al.* (STAR Collaboration), *Phys. Rev. C* **77**, 054901 (2008).